AD-A105 497 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 5/11
INNOVATIVE/ALTERNATIVE WASTEWATER COLLECTION SYSTEMS FOR CORPS --ETC(U)
SEP 81 M J CULLINANE
UNCLASSIFIED WES/MP/EL-81-7 NL

1 OF 1
AD A
105497

END
DATE
FILMED
11-81
DTIC

MISCELLANEOUS PAPER EL-81-7

INNOVATIVE/ALTERNATIVE WASTEWATER COLLECTION SYSTEMS FOR CORPS OF ENGINEERS RECREATION AREAS

by

M. John Cullinane, Jr.

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1981

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under Work Unit 31687

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) (14) WES/MP/EL-81-7

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Miscellaneous Paper EL-81-7	2. GOVT ACCESSION NO. AD-A105 497	3. RECIPI[redacted]NT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) INNOVATIVE/ALTERNATIVE WASTEWATER COLLECTION SYSTEMS FOR CORPS OF ENGINEERS RECREATION AREAS		5. TYPE OF [redacted]ORT & PERIOD COVERED Final rep[redacted]t
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) M. John Cullinane, Jr		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit 31687
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE (11) Sept[redacted]981
		13. NUMBER OF PAGES 36
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 47		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Recreational facilities
Sewage disposal
Sewage effluents
Waste water
Waste water disposal

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The design of waterborne waste carriage systems has traditionally incorporated the use of gravity collection and transmission systems. Geological and topographic constraints may indicate use of innovative collection alternatives such as pressure, vacuum, or small-diameter systems. General design considerations and evaluation factors are presented for each collection and transmission alternative. Pressure and vacuum systems may provide cost-effective alternatives to gravity collection in Corps of Engineer recreation areas. Alternatives must be evaluated on a cost-specific basis.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

411 3 6

PREFACE

The study reported herein was funded by the Office, Chief of Engineers, U. S. Army, from Civil Works Appropriation 96X3123, "General Investigations - Research and Development," Work Unit 31687, "Innovative/Alternative Wastewater Collection, Transportation, and Treatment Systems for Recreation Areas."

The study was conducted during 1980 by personnel of the Environmental Engineering Division (EED) of the Environmental Laboratory (EL), U. S. Army Engineer Waterways Experiment Station (WES).

The study was conducted by Mr. M. John Cullinane, Jr., under the direct supervision of Mr. Norman R. Francingues, Chief, Water Supply and Waste Treatment Group, and the general supervision of Mr. Andrew J. Green, Chief, EED, and Dr. John Harrison, Chief, EL.

Commander and Director of WES during the study and preparation of this report was COL N. P. Conover, CE. Technical Director was Mr. F. R. Brown.

This report should be cited as follows:

Cullinane, M. J., Jr. 1981. "Innovative/Alternative Wastewater Collection Systems for Corps of Engineers Recreation Areas," Miscellaneous Paper EL-81-7, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per foot	0.3048	metres per metre
feet per second	0.3048	metres per second
gallons (U. S. liquid)	0.003785412	cubic metres
gallons (U. S. liquid) per day	0.00000004381	cubic metres per second
gallons per minute	0.00006309	cubic metres per second
horsepower (electric)	746.0	watts
inches	0.0254	metres

INNOVATIVE/ALTERNATIVE WASTEWATER COLLECTION SYSTEMS FOR CORPS OF ENGINEERS RECREATION AREAS

PART I: INTRODUCTION

Background

1. The objective of a wastewater collection system is to convey wastes from the point of generation to the point of treatment or disposal. Depending on site conditions and economics, the U. S. Army Corps of Engineers (CE) has traditionally used either trucked transport or gravity pipe systems for collection and transmission of wastewaters. The use of trucked transport systems is limited to small volumes of wastes that may be classified into four categories: septic tank sludge (septage), vault toilet wastes, recirculating and portable chemical toilet wastes, and isolated low-volume flush toilet wastes. Gravity pipe systems also include associated pumping stations and force mains and are generally used for waterborne waste carriage.

2. Gravity sewer systems consist of a network of underground pipes that slope continually downhill to some termination point. To obtain proper flow velocities, piping must be installed with sufficient slope in spite of the topographic and geologic characteristics of the site. Although a system in which the necessary energy is supplied entirely by gravity is the ideal, usually gravity systems must incorporate lift stations and force mains along the way to avoid deep excavations that would be necessary in flat or undulating terrain.

3. The topography and geology of many CE recreation areas are complex and not well suited for economical use of gravity wastewater collection systems. The very characteristics that make for an esthetically pleasing recreation area complicate the design and construction of necessary sanitary facilities. Hilly or rocky terrain may increase the cost of construction of traditionally designed gravity sewers, making otherwise desirable locations unsuitable for development as recreation

areas (Office, Chief of Engineers 1980).

4. Various innovative/alternative (I/A) wastewater collection technologies have been developed for municipal applications to provide cost-effective collection systems where topographic, geologic, or development density constraints had previously been found to make traditional collection systems economically infeasible. These same types of systems can be applied with little if any research and development effort to the collection and transportation of wastewater generated at recreation area installations.

Purpose

5. One of the purposes of Work Unit 31687, "Innovative/Alternative Wastewater Collection, Transportation, and Treatment Systems for Recreation Areas," is to develop and disseminate information concerning the applicability of I/A wastewater collection systems to the requirements of CE recreation areas. The initial year of the I/A collection system study was designed to:

- a. Identify available I/A wastewater collection concepts.
- b. Evaluate the applicability of I/A wastewater collection system alternatives to the CE recreation area scenario.
- c. Identify research and development requirements necessary for effective implementation of technically feasible I/A collection systems to meet CE recreation area needs.

6. The purpose of this report is to present a summary of the findings and conclusions concerning the applicability of I/A wastewater collection systems to the typical CE recreation area scenario.

Approach

7. The following five-phase study was designed to accomplish the basic purpose of the initial year of this work unit:

- a. Phase I. Conduct a review of available literature concerning I/A collection techniques.

b. Phase II. Conduct interviews with appropriate field personnel concerning application of I/A collection technology.

c. Phase III. Evaluate the technical and economic viability of identified I/A technologies.

d. Phase IV. Develop interim guidance for evaluating the site-specific applicability of I/A collection technologies.

e. Phase V. Identify research and development requirements related to use of I/A collection techniques at CE recreation areas.

PART II: CONVENTIONAL COLLECTION SYSTEMS

8. Conventional wastewater collection systems are generally composed of gravity sewers, lift stations, and force mains. The gravity sewer, which constitutes the major portion of most conventional collection systems, consists of a network of underground pipes that slope continually downhill to some terminus where the wastewaters are either treated or disposed of in some acceptable manner.

System Design

Gravity system

9. Piping design. The first requirement of a gravity sewer system is that it be capable of carrying the present and anticipated design flow of the area it is to serve. Manning's and Kutter's equations are the most widely used expressions to determine the velocity in a sewer line, with Manning's equation in wider usage because of its simplicity. Manning's equation is

$$V = \frac{1486}{n} R^{2/3} S^{1/2}$$

where

V = velocity, fps

n = coefficient of pipe roughness

R = hydraulic radius, ft = $\frac{\text{cross-sectional area}}{\text{wetted perimeter}}$

S = slope of the energy grade line, ft/ft

Many textbooks and design manuals include nomographs for computation of pipe sizes and velocities for any slope of flow condition.

10. A Manning's n of 0.013 is recommended for design of new sewers whereas a value of 0.015 is generally used for evaluation of existing systems. The recommended design value (n = 0.013) is based on use of pipe having laying lengths of not less than 5 ft* with true and

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

smooth inside surfaces. Higher values of n should be used in the evaluation of sewers if it is evident that the lines are deteriorated, laid on irregular grades, or filled with deposits or if inferior workmanship is evident (American Society of Civil Engineers (ASCE) 1974).

11. Maintenance of a minimum velocity of 2.0 fps is perhaps the most critical design criterion for gravity sewerage systems. This minimum velocity is necessary in order to prevent deposition of solids and resultant reduction in flow carrying capacity. Many times, conditions at recreation areas require sewers with flat slopes in order to avoid excessive excavation, to provide minimum cover, or to satisfy other flat terrain constraints. Minimum recommended slopes for various sizes of sewer pipe are given in the following tabulation (GLUMRB 1978):

Pipe Size, in.	Slope, ft/ft
6	0.006
8	0.004
10	0.003
12	0.0022
15	0.0015
18	0.0012
21	0.0010
24	0.0008

12. Erosion of pipe materials due to excessive velocities may also present design problems when gravity sewers must be installed in steep terrain. A maximum velocity limit of 10 fps should be adhered to where grit erosion is probable.

13. Appurtenances. Appurtenances associated with sanitary sewers include manholes, building connections, and junction boxes. The principal appurtenance found in recreation areas is the manhole, either the regular or drop variety.

14. A manhole is an opening constructed in a sewer to provide access for cleaning, inspection, and maintenance of sewer lines. Manholes are required on small sewer lines at changes in size, slope, or direction. Manholes should be installed so as to cause a minimum of

interference with the hydraulics of sewers. Manholes are generally precast with rubber compression joints. Maximum spacing is generally 350 ft on lines less than 24 in. in diameter (Metcalf and Eddy 1972).

15. Materials of construction. The most common types of pipe materials available for construction of conventional wastewater collection systems include the following: vitrified clay, concrete, ductile iron, solid-wall plastic, truss pipe, and asbestos cement. In general, concrete, asbestos cement, and ductile iron pipe may be subject to external and internal corrosion if used without some type of coating. The most common materials used for conventional sanitary sewers are vitrified clay and plastic materials.

16. Vitrified clay pipe is available in diameters from 4 to 36 in. It has a smooth surface that offers good flow characteristics; it is resistant to erosion and scour and to acids and sewer gases. However, vitrified clay pipe is brittle and has a limited range of strength. In recreational areas this liability will probably not be a factor. Another disadvantage is that short laying lengths are required, resulting in a high number of joints per 100 linear feet, which makes it difficult to satisfy infiltration requirements (ASCE 1974).

17. Recently, the use of solid-wall plastic pipe in sewers has increased. Solid-wall plastic pipe is lightweight, makes tight joints, does not require short laying lengths, is resistant to scour and corrosion, and has good flow characteristics. Disadvantages are thin walls, susceptibility to deterioration from exposure to sunlight, limited sizes, and stringent bedding requirements.

18. Truss pipe is manufactured by extruding acrylo-butadiene styrene (ABS) thermoplastic into a truss with inner and outer walls connected by webs. The voids are filled with lightweight filler. The pipe is usually jointed by a compression gasket. Diameters range from 8 to 15 in. Advantages and disadvantages are the same as those for solid-wall plastic pipe.

19. Pipe of asbestos fiber and cement is available in diameters from 4 to 36 in. Asbestos cement pipe is jointed by rubber compression gaskets. The advantages of asbestos cement pipe are lightweight and

ease of handling, long laying lengths in some situations, tight joints, and a wide range of available strength classifications. The major disadvantage of asbestos cement pipe is its susceptibility to corrosion where acids or hydrogen sulfide is present. Asbestos cement pipe is specified by pipe diameter, class or strength, and type of joint (ASCE 1974).

20. Nonreinforced concrete pipe from 4 to 24 in. in diameter and reinforced concrete pipe from 12 to 144 in. in diameter are available generally in circular cross sections for gravity sewers. A number of jointing methods are available, depending on the tightness required. The advantages of concrete pipe are the relative ease with which the required strength may be provided and the wide range of sizes and laying lengths available. A disadvantage is that it may be subject to corrosion where acids or hydrogen sulfide is present. Protective linings of proven performance are available for use where these conditions exist. Concrete pipe is specified by pipe diameter, class or strength, the method of jointing, and any special lining or concrete requirement (ASCE 1974).

21. Installation and testing. Improper installation and testing are the primary causes of sewer system failure. Attention must be given to such items as alignment, bedding, backfill, grade, and jointing. Pipe should be laid progressively upgrade, with bell upstream to form closed, concentric joints with smooth bottom inverts. Pipe embedment and backfilling should closely follow the installation and jointing of pipe in the trench. Sufficient cover should be provided to prevent freezing and/or crushing of the pipe by external loads. A sound rule of thumb is that no more than 400 ft of pipe should be exposed ahead of backfilling in any section of trench. Bedding and backfill to a minimum of 1 ft above the top of pipe should be select granular material compacted. Trench widths should be the minimum necessary for efficient working conditions. Occupational Safety and Health Administration regulations should be consulted for sheeting and shoring requirements.

22. After backfill has been placed, the gravity flow lines must be checked for proper alignment and grade. Significant attention must

be given to testing for susceptibility to infiltration/inflow.

Lift stations

23. Invariably the design of conventional wastewater collection systems encompasses the use of lift stations to impart the necessary energy to the wastewater to move it to the point of treatment or disposal. In areas where the terrain is either extremely hilly or flat, placement of lift stations in series may not be uncommon.

24. Two basic types of pumps are used in wastewater collection: centrifugal and pneumatic ejector pumps. Centrifugal pumps propel the wastewater by the action of centrifugal force using an impeller, casing, and drive system. Pneumatic ejectors propel the wastewater by the action of air pressure using a collection tank, air compressor, and ball valve arrangement. Each pump has its own power requirements, efficiency, head, and pumping rate. The manufacturer's catalog should be consulted for selection of pumps.

25. The lift station wet well serves as a wastewater receiving station, equalizing basin, and pit from which the wastewater is withdrawn by the pumps. Wet wells are generally sized as a function of pump motor cycle time requirements, which are in turn a function of pump motor size. The size of pumps normally found in recreation facilities generally requires a 3- to 5-min cycle time. Thus, the pump and wet well combination must be designed in such a fashion that the pump will run a minimum of 3 to 5 min before cutoff. For best energy efficiency, pumps should be designed to run for long periods of time, and, ideally, the capacity of the pump would equal the wastewater inflow rate.

Force mains

26. A force main, which is generally associated with each lift station, is essentially a pipe carrying wastewater under the pressure imparted by the pumps at the lift station. A variety of materials are available for force main construction including asbestos cement, concrete, ductile iron, steel, and solid-wall plastic pipe. Perhaps the most common materials used for those flow ranges associated with recreation facilities are cast or ductile iron and solid-wall plastic pipe.

System Costs

27. The cost of conventional gravity collection may be evaluated by considering the possible component parts. The major component parts are the gravity piping and appurtenances, pumping stations, and force mains.

Gravity piping

28. The cost of gravity piping is primarily a function of pipe size and depth. The following tabulation presents typical unit costs for 8-in.-diam vitrified clay and ABS truss pipe for depths of burial up to 12 ft based on recent bid prices (July 1980). Figure 1 presents the relationship between installation costs and depth of burial of conventional gravity collection systems.

Depth ft	Vitrified clay dol/lin ft	ABS Truss Pipe dol/lin ft
0- 6	9.25 - 16.00	6.90 - 10.00
6- 8	10.00 - 16.95	8.60 - 11.00
8-10	12.10 - 23.00	9.70 - 12.50
10-12	15.00 - 30.00	12.10 - 16.00

29. The cost of appurtenances consists primarily of manholes. The following tabulation presents typical costs quoted for construction of a 48-in.-diam manhole (July 1980).

Depth ft	Estimated Cost Range, dol
0- 6	500 - 655
6- 8	600 - 802
8-10	700 - 943
10-12	800 - 1084

Force mains

30. Force main costs can be estimated as a function of pipe size and material. Depth of burial is generally not a determining factor since force mains can generally be buried at a minimal depth to provide protection from frost or concentrated loads. The estimated costs, based on July 1980 prices, of polyvinyl chloride (PVC) force mains buried at

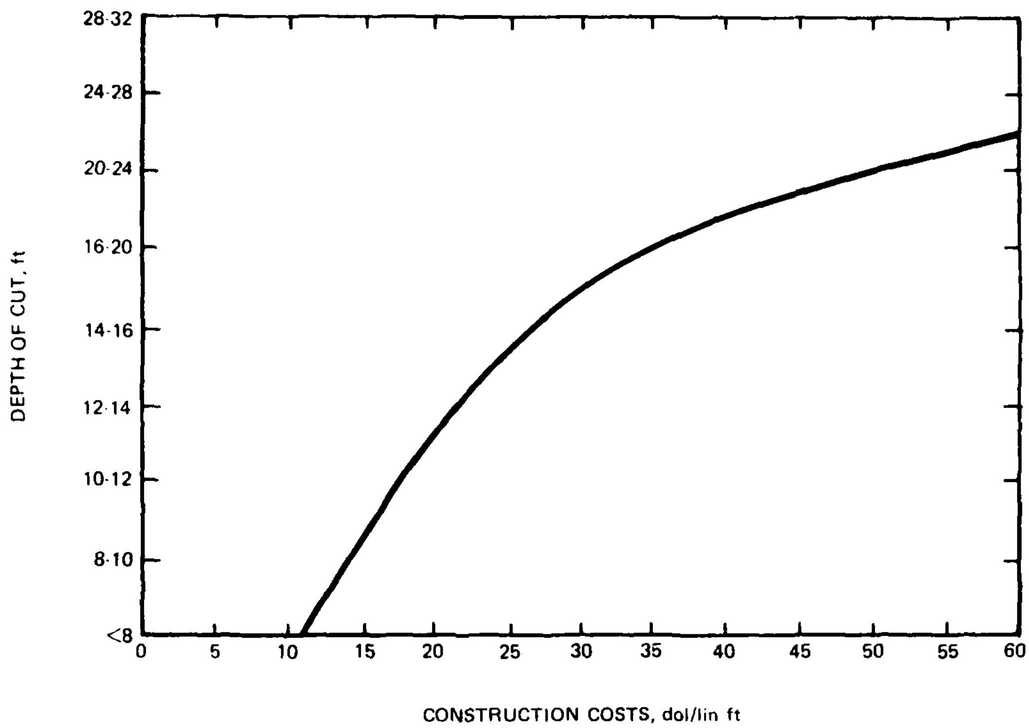


Figure 1. Relationship between gravity sewer construction costs and depth of installation (from Kriessel, Cooper, and Reyek 1977)

4 ft are presented in the following tabulation:

Diameter in.	SDR25 dol/lin ft	SDR18 dol/lin ft
4	3.00 - 4.00	4.50 - 5.50
6	5.00 - 6.00	6.00 - 7.00
8	7.50 - 8.50	10.00 - 11.00
10	10.00 - 11.00	13.00 - 14.00

Lift stations

31. Pumping station costs are primarily a function of system capacity and depth of the station. For those flows associated with recreation areas, pump station costs are estimated to range from $12,000 to $17,000 for typical self-priming pump (wet pit) stations and $9,000 to $12,000 for submersible pump stations. Pneumatic ejector systems are expected to cost from 10 to 25 percent more than centrifugal stations.

Costs may be higher where depths of installation are excessive or unusual soil conditions exist. These prices are based on manufacturers' quotes received in July 1980.*

Evaluation of Gravity Collection Systems

32. In summary, the use of gravity collection systems represents the traditional approach to carriage of waterborne wastes. The cost of such systems is primarily a function of system length and topography rather than pipe size. The cost of gravity systems must be evaluated on a site-specific basis. Qualitatively, however, it may be stated that (National Utility Contractors Association (NUCA) 1979):

- a. Gravity sewers are uncomplicated and easy to maintain, and do not require skilled operators.
- b. Gravity sewers have ample flow-handling capabilities to permit expansion and growth.
- c. Sewage transport occurs under aerobic conditions, which minimizes corrosion problems at the treatment facility.
- d. Little or no power is required for gravity systems. Power outages have little impact on the system.
- e. Gravity sewers have high capital costs, especially if terrain or excavation problems are encountered. If deep excavation and/or lift stations are required, other collection systems may be more cost-effective.
- f. Infiltration inflow can cause significant wastewater dilution and increase the hydraulic load at the treatment facility.

---

* Personal communication dated 15 July 1980 from Mr. Charles Stone, Mississippi Pump and Equipment Co., Jackson, Miss.

PART III: INNOVATIVE/ALTERNATIVE SYSTEMS

Background

33. A gravity flow sewer system is usually considered first when waterborne waste disposal is to be provided. Unfortunately, unique site-specific constraints found at many CE recreation areas, such as topography, geology, low population density, and intermittent system use, discourage consideration of conventional gravity flow concepts.

34. The designer of gravity flow sewer systems is faced with many constraints, particularly where site conditions are severe. Typical constraints include the following:

- a. Larger pipe sizes than the volume of sewage will normally fill are required.
- b. Pipe must be laid along precise grades.
- c. Piping must be placed in special bedding material.
- d. Manholes must be provided at frequent intervals.
- e. Deep cuts may require excessive right-of-way, resulting in greater environmental damage.

These technical limitations make gravity flow systems costly for many CE applications.

35. Collection and transport systems that overcome the technical limitations of gravity flow systems have been developed for use in municipal applications. Three systems have received the greatest attention from both the research and development and practical application viewpoints (NUCA 1979):

- a. Low pressure-small diameter systems.
- b. Vacuum systems.
- c. Small-diameter gravity systems.

Pressure Systems

36. Pressure collection systems use low pressure provided by small pumps to assist in the collection and transmission of the generated

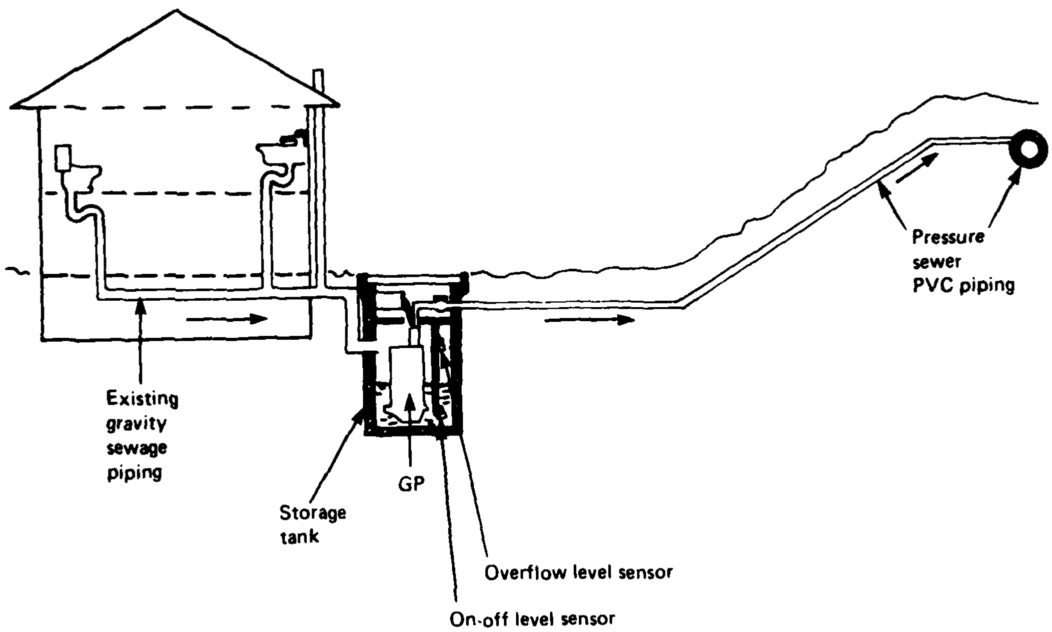
wastewaters. Pressure sewer systems are analogous to water treatment distribution systems operating in reverse (Kriessel, Cooper, and Reyek 1977). A pump is required at each point of entry of the wastewater into the collection system. The collection system eventually empties into a larger pumping station used to feed the treatment facility. Because pressure sewers transmit wastes independent of terrain constraints, they are most commonly used for lakeside communities where flow must travel uphill, areas with very hilly or very flat terrain, or areas where excavation is hindered by high water tables. The primary advantage of pressure sewer systems is the reduction in excavation and pipe installation costs.

37. Positive pressure sewer systems eliminate the need to lay pipe to hydraulic grade lines and the necessity for intermediate pumping stations associated with conventional gravity collection systems. Smaller diameter (usually 3 in.) PVC pipe is substituted for larger diameter vitrified clay or concrete pipe generally used in gravity systems. The use of small PVC pipe with solvent welded or compression joints, the absence of manholes, and the low-pressure environment virtually eliminate infiltration/inflow in pressure systems. Unfortunately, the advantages of these design features are offset by electrical equipment required at every sewage input point in the collection system.

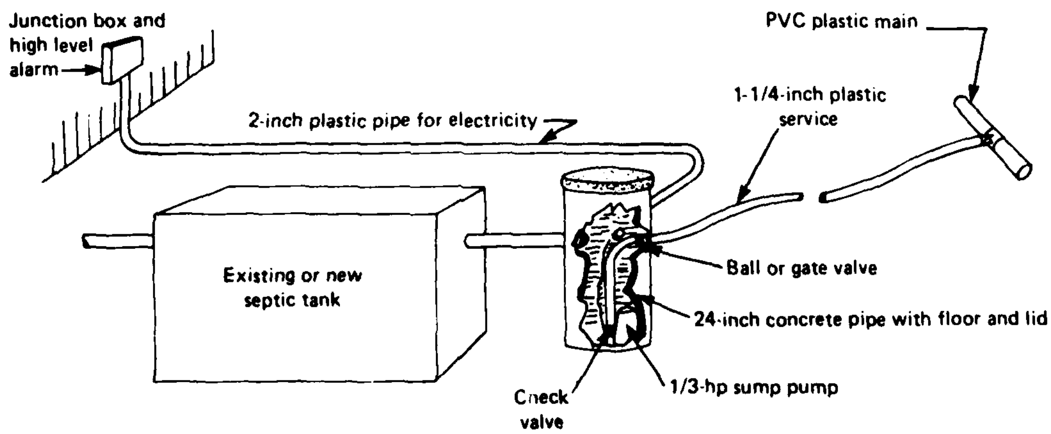
38. Pressure sewer systems have two principal components, an on-site pressurization system and small-diameter pressurized collectors. The on-site pressurization unit serves two basic functions: removing objects capable of lodging in the small-diameter piping system and providing the pressure necessary to drive the wastewater through the piping system. Two basic concepts are available for pressure system design (Figure 2). The first uses a grinder pump (GP) to grind the wastes into a slurry and then pump the slurry through the piping system. The second uses a septic tank for anaerobic pretreatment prior to injection of the wastes into the collection system with small centrifugal pumps. This septic tank-effluent pumping (STEP) system has proven to be more reliable in field studies and is rapidly replacing the GP systems.

System components

39. GP systems. GP systems consist of a holding tank, the grinder



a. GP installation



b. STEP system

Figure 2. Typical components of pressure sewer systems (from Kriessel, Cooper, and Reyek 1977)

pump, associated electrical and mechanical appurtenances, and the collection system piping (Hydr-O-Matic 1978). The grinder pump is installed slightly above the bottom of the holding tank, which may be located in a building basement or separate subsurface structure. The holding tank receives wastewater flows by gravity. Level sensors activate the operation of the grinder pump at preset levels. Emergency overflow and high level alarms should be provided. Check valves are provided in the piping system directly after the grinder pump.

40. Grinder pumps are either the submersible centrifugal type or the positive displacement type (Hydr-O-Matic 1978). The centrifugal type pumps operate at reduced delivery at high system heads whereas the positive displacement pumps provide a constant delivery relatively independent of system head. System designs vary among manufacturers, dependent upon the characteristics of the particular manufacturer's product.

41. The collection piping for the GP system consists of the service connection including a check valve and the pressure main. The system is generally constructed of PVC pipe; however, polyethylene has been successfully used on occasion. Service connections may vary from 1-1/2 to 4 in. depending on wastewater flow to be pumped from an individual facility. The pressure main may be as large as 12 in. in diameter. No manholes are required.

42. STEP systems. STEP systems consist of a conventional septic tank, the on-site pressurization unit, and the collection system piping. In the STEP system, generated wastewaters are collected by the building drain system and transported to a septic tank. The septic tank provides significant levels of treatment by removing from 80 to 90 percent of the grease, 70 to 90 percent of the suspended solids, and 50 to 80 percent of the biochemical oxygen demand (BOD) (Kriessel, Cooper, and Reyek 1977). The septic tank effluent then flows to the on-site pressurization unit for injection into the pressurized collection system. In essence, the STEP concept removes large solids and other objects via sedimentation rather than reducing the size of the objects as in the case of the GP system.

43. STEP systems use either nonclog submersible centrifugal sewage pumps or pneumatic ejectors (Peabody Barnes 1977). Because STEP pumps

handle only supernatant from the septic tanks, these pumps are generally smaller and require less maintenance than grinder pumps.

44. The collection piping for the STEP system is essentially the same as provided for the GP system.

Design concepts

45. Information requirements. Information requirements for design of pressure sewer systems are similar to those of conventional gravity sewers. The following information is required before final design (Peabody Barnes 1977):

a. Topographic map of the area to be served.

b. Site plan indicating locations of wastewater generating facilities.

c. Soil and water table conditions.

d. Location of wastewater treatment plant.

e. Types of wastewater generating facilities to be served.

f. Climatic conditions (frostline).

g. Location of present utilities including sewer systems.

h. Power requirements, location of existing power source, and power outage data.

i. Applicable local, state, and Federal codes and construction criteria.

j. Type of system (total pressure or pressure-gravity combination) and proposed system layout.

46. System layout and alignment. Pressure sewer systems are generally designed as branched systems. Looped systems similar to water systems are technically feasible; however, branched systems are considered to have operation and maintenance advantages. If problems develop in one of the branches, the branch can be isolated for repair without affecting the remainder of the system. The branches and mains should be laid out to provide the shortest run and the fewest changes of direction.

47. A major constraint in the layout and alignment of pressure sewer systems is the maintenance of positive pressure. The maintenance of positive pressure prevents air plating of solids and grease, potential air accumulation at high points, and possible siphoning effects on

pumping units (Peabody Barnes 1977). Positive pressure can be maintained through the use of positive pressure regulating valves or by locating the system terminus at the highest point in the system.

48. Air accumulation at system high points has a detrimental impact on the operation of pressure systems. The number of high points can be minimized by installing piping on a continuously rising grade whenever possible. Precise survey profiles are not necessary. Although air accumulated at system high points can be purged with sufficient wastewater velocities, some form of air relief at major high points should be provided (Hydr-O-Matic 1978).

49. Design flow. The most critical design parameter for pressure sewer systems is design flow. The design of pressure systems is somewhat more sensitive than gravity systems to errors in the determination of design flow. The system must be designed to handle the peak flow as well as the average flow from each facility. This can be accomplished by either accurately predicting the peak flow or ensuring adequate storage in the on-site holding tank to prevent backup or overflow of wastewater during periods of peak flow. STEP systems have an added advantage over GP systems because they normally have more than 24-hr storage capacity in the associated septic tank.

50. Calculation of design flows at recreation areas continues to present significant problems for the CE planners or engineers. EM 1110-2-501 Part 2 of 3 (Office, Chief of Engineers, U. S. Army 1980) contains detailed guidance on the calculation of design flows from various sanitary facility types. The fixture unit method of calculating wastewater flows is most appropriate for calculating peak flows whereas the per capita method is more applicable to calculation of average daily flows. The calculation of design flows, however, continues to be more art than science. Flow calculation examples are presented in EM 1110-2-501 Part 2 of 3 (1980).

51. Velocities and head loss. The design of pressure system piping systems is normally based on a compromise between maintenance of scouring velocities and minimization of head loss. Maintenance of scouring velocities is particularly important for GP systems where grease

and solids may present problems in system operation. Head loss calculations for each system follow conventional hydraulic design procedures.

52. Minimum scouring velocities can be estimated by the following equation (Kriessel, Cooper, and Reyek 1977):

$$V_s = \sqrt{D}/2$$

where

V_s = minimum scouring velocity, fps

D = inside diameter of pipe, in.

System operational experience indicates that a minimum velocity of 2 fps should be maintained if at all possible.

53. Head loss calculations for pressure sewer systems are generally based on the Hazin-Williams formula. For PVC pipe or other smooth pipe, a Hazin-Williams C factor of 150 or 140 is normally used. Peabody Barnes (1977) recommends using a C of 150 for STEP systems. Using a C of 140 for the GP systems provides a safety factor for anticipated grease and solid buildup problems. Since the design of pressure sewer systems is not an exact science, individual paths through the system should not have a total head loss of more than 85 percent of pump shutoff head capacity. Static heads as high as 100 ft have been attempted.

54. Miscellaneous considerations. Because the collector network is pressurized, pipes must flow at full capacity. If the diameters of the collector and transmission pipes are small, the residence time of the waste in the collection system is minimized and the required scouring velocity is reduced. Because the wastewater is under pressure, pressure sewers can be laid uphill or on level terrain. Shallow burial depths, generally only sufficient to protect the system from freezing, are required. Thus, the costs of pressure sewers are much less affected by excavation expenses than are those of conventional gravity sewer systems.

55. Several major design problems are associated with the application of pressure sewers. Service area expansion may be limited.

Pressure main leakage may pose a significant groundwater contamination problem due to the positive system pressures. Hydraulic considerations are more critical in design of pressure systems than in design of gravity systems. Under peak flow conditions, excessive pressures can build up causing reduced pumping rates or even pump shutoff, resulting in holding basin overflow. During low flow periods, minimum scouring velocities are difficult to maintain, possibly causing solids deposition and line plugging. Where minimum velocities cannot be maintained, flushing units may be required for periodic collection line cleaning.

System costs

56. The total costs associated with pressure sewer systems are not well defined at the present time. The data that are available will generally be limited to planning level estimates rather than actual construction and operating data.

57. Capital costs. In determining the capital costs associated with system construction, the cost of individual components must be evaluated. As discussed previously, system components may include grinder pumps, effluent pumps, septic tanks, and the piping system. The costs presented in the following discussion are based on July 1980 manufacturers' information.

58. Grinder pumps are purchased in two basic sizes. Typical of most residential systems is the 2-hp single household pump estimated to cost between $2,000 and $3,000 installed. Larger grinder pump systems up to 5 hp (175 gpm at 45 ft total dynamic head) are also available at an estimated installed cost ranging from $9,000 to $12,000 for a duplex unit.

59. The on-site portions of STEP systems are estimated to cost between $2,000 and $3,000 with a cost for equipment ranging from $1,000 to $2,000 and installation costing $1,000. The STEP system includes both the effluent pump and septic tank.

60. The capital cost of the piping systems may be estimated by dividing the system into the service connection component and the pressure main component. The cost of the pressure main may be determined on a per linear foot basis. Cost estimating procedures are similar to those

used for estimating the costs of water transmission and distribution systems and are generally a function of pipe diameter and depth of burial. The tabulation in paragraph 30 can be used to estimate the cost per linear foot of pressure main installation.

61. The cost of service connections can also be calculated per linear foot. Assuming use of 1-1/4-in. to 3-in. PVC piping service connections, the cost per linear foot of service connections is estimated to range between $1.50 and $3.00.

62. Operation and maintenance. Operation and maintenance costs associated with pressure sewer systems are even less well defined than system construction costs. Varying estimates have been provided by numerous authors.

63. Grinder pump maintenance is estimated to range between $6.00 and $10.00 per unit per month. Operation costs consist primarily of power utilization, which is a function of pump size and quantity of wastewater pumped. Power requirements have been estimated to be 1 watt per gallon. Total power cost may be determined by multiplying the volume of wastewater pumped, in gallons, times the cost per watt of electricity. Service manpower for grinder pumps has been estimated to average one man-day per year (Kriessel, Cooper, and Reyek 1977).

64. The operation and maintenance costs associated with STEP systems are estimated to be somewhat less than GP operation and maintenance costs. Estimates range between $50.00 and $75.00 per year for pump maintenance and septic tank cleaning every 5 to 10 years at a cost of $30.00 to $50.00 per cleanout. Power requirements are estimated to be 0.5 watt per gallon of wastewater pumped. Service manpower is estimated to be 0.5 man-day per year per pump unit (Kriessel, Cooper, and Reyek 1977).

65. Operation and maintenance costs associated with the pressure main and service connections are ill defined; however, they are likely to be less than operation and maintenance on conventional gravity flow systems. Estimates of pressure system operation and maintenance costs range from $100.00 to $150.00 per mile per year as compared with gravity system costs of $400.00 per mile per year. Operation and maintenance costs for STEP pressure mains should be less than those for similar GP

systems because most of the problem-causing materials are removed in the septic tank.

Vacuum Systems

66. Vacuum collection systems depend on a central vacuum source to maintain a constant vacuum on the main line of the collection system. The system is similar to positive pressure systems in that the collection lines are small-diameter plastic pipe that can be laid independent of hydraulic grade. Four basic systems are manufactured and patented in the United States: Liljendahl-Electrolux, Colt Envirovac, AIRVAC, and Vac-Q-Tec. Each system has several distinguishing features (NUCA 1979).

67. Figure 3 illustrates the elements of a typical vacuum sewage system. A gravity-vacuum interface valve separates atmospheric pressure from the vacuum on the mains. The valve can be either in the home sanitary sewer service line or in a vacuum toilet. When the interface valve opens, a volume of sewage enters the main, followed by a volume of atmospheric air. After a preset interval, the valve closes. The packet

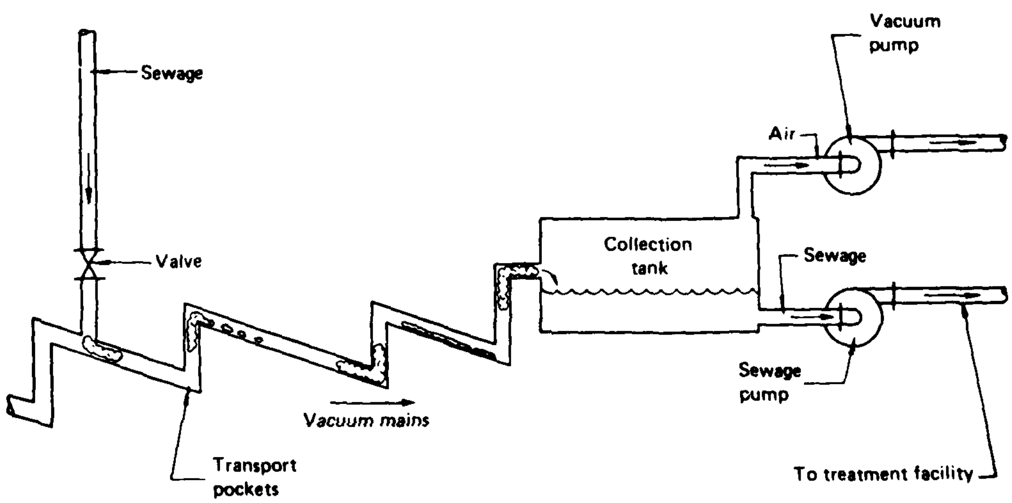


Figure 3. Typical elements of a vacuum sewage system (from Kriessel, Cooper, and Reyek 1977)

of liquid, called a slug, is propelled into the main by the differential pressure of vacuum in the main and the higher pressure atmospheric air behind the slug. After a distance, the slug breaks down by shear and gravitational forces, allowing the higher pressure air behind the slug to slip past the liquid. With no differential pressure, the liquid flows to the lowest local elevation, and vacuum is restored to the interface valve for subsequent operations. When the next upstream interface valve opens, identical actions occur, with that slug breaking down and air rushing across the second slug. That air impacts the first slug and forces it further downstream. After a number of operations, the first slug arrives at the central vacuum source. When sufficient wastewater is accumulated in the collection tank at the central vacuum source, the collected wastewater is pumped to the point of treatment.

System components

68. All four vacuum systems have three main components: a central vacuum source, vacuum collection mains, and on-site vacuum valves. A generalized schematic diagram of the AIRVAC system is presented in Figure 4.

69. Vacuum valves are generally set at the bottom of a

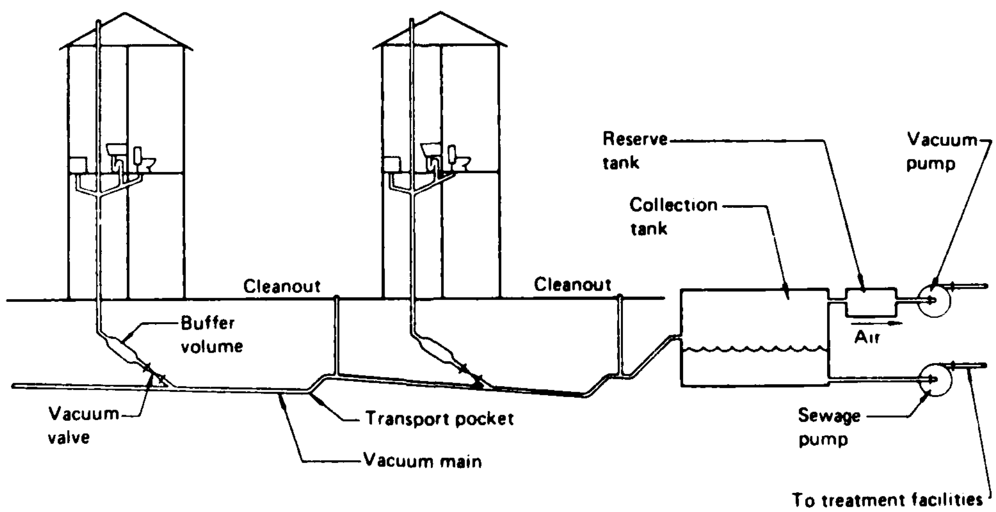


Figure 4. Typical schematic of an AIRVAC vacuum collection system (from Kriessel, Cooper, and Reyek 1977)

variable-size holding basin and are functionally equivalent to the on-site structures of GP pressure systems. Valves remain closed until a preset level of wastewater is accumulated in the holding basin. A pressure-sensing device is triggered by wastewater levels in the holding basin. When a certain level is reached, the valve opens and the wastewater is sucked into the collection system. The valve remains open long enough to completely drain the holding basin of wastewater and to admit a variable amount of air. The valve and associated on-site structure represent approximately half of the vacuum system costs.

70. The two vacuum valve designs presently in operation are the diaphragm valve used by Vac-Q-Tec, and the piston design, originally developed by Electrolux and subsequently improved by Colt-Envirovac and AIRVAC. Considerable operational difficulties have been encountered with vacuum valve design. The AIRVAC valve appears to be more reliable and maintenance free. The AIRVAC system incorporates a timing device to regulate valve closure, which is activated by a three-way control valve. Holding basins have a 30- to 60-gal capacity and valves are actuated when 10 to 15 gal of wastewater has accumulated. Average operation time is about 6 sec and depends on the amount of air to be admitted to the system.

<u>Design considerations</u>

71. <u>Information requirements and design flow.</u> Information requirements and calculation of design flows for vacuum systems are essentially the same as for pressure systems. Design flows for vacuum systems may be somewhat different since water-saving fixtures are generally incorporated in the system design whenever a vacuum system is completed.

72. <u>System layout and alignment.</u> Three basic and distinct vacuum collection system configurations are available (Skillman 1979):

- a. A single-pipe system where only vacuum toilets are connected to a vacuum system.
- b. A dual-pipe system where grey-water and black-water sources are connected to the vacuum system, but are transported in separate piping systems.
- c. A single-pipe system combining the two types of wastewater

into a common transfer main using conventional fixtures along with gravity-fed intermediate holding or storage tanks.

Each system possesses its own fundamental design requirements.

73. Vacuum system piping alignment and profiles must be better defined than those found in pressure systems due to the more complicated system hydraulics. A typical system profile is illustrated in Figure 5. Static lift, friction losses, minimum vacuum requirements, and leakage all place constraints on sewer length and lift. Maximum sewer lengths between vacuum stations may range from 1,000 to 3,000 ft. Maximum lift is 14 to 16 ft for one continuous length of pipe.

74. The Naval Facilities Engineer Command (Skillman 1979) is conducting research on generic design of vacuum systems for advance based applications. However, until this research is completed, each manufacturer should be consulted to determine appropriate design procedure.

75. Miscellaneous. Vacuum systems have not been as widely applied or researched as pressure sewer systems. Design parameters and hydraulic characteristics are not well defined. The general design constraints may limit their utility in combination with the collection systems.

System costs

76. The costs associated with vacuum collection technology are not well defined at the present time. Vacuum systems are proprietary and specific system costs may be obtained only from the manufacturer of the system. Significant cost savings have been reported for community system applications. Because of the complexity of vacuum equipment, operation and maintenance costs and skill requirements are expected to be high.

77. The CE has selected vacuum sewer technology for recreation areas located at Blue Marsh Lake (Philadelphia District) and Cowanesque Lake (Baltimore District). These systems were implemented under the CE value engineering program. The major anticipated savings result from the reduction in the amount of water required by vacuum systems and resulting reduction in wastewater treatment costs. Wastewater generation was

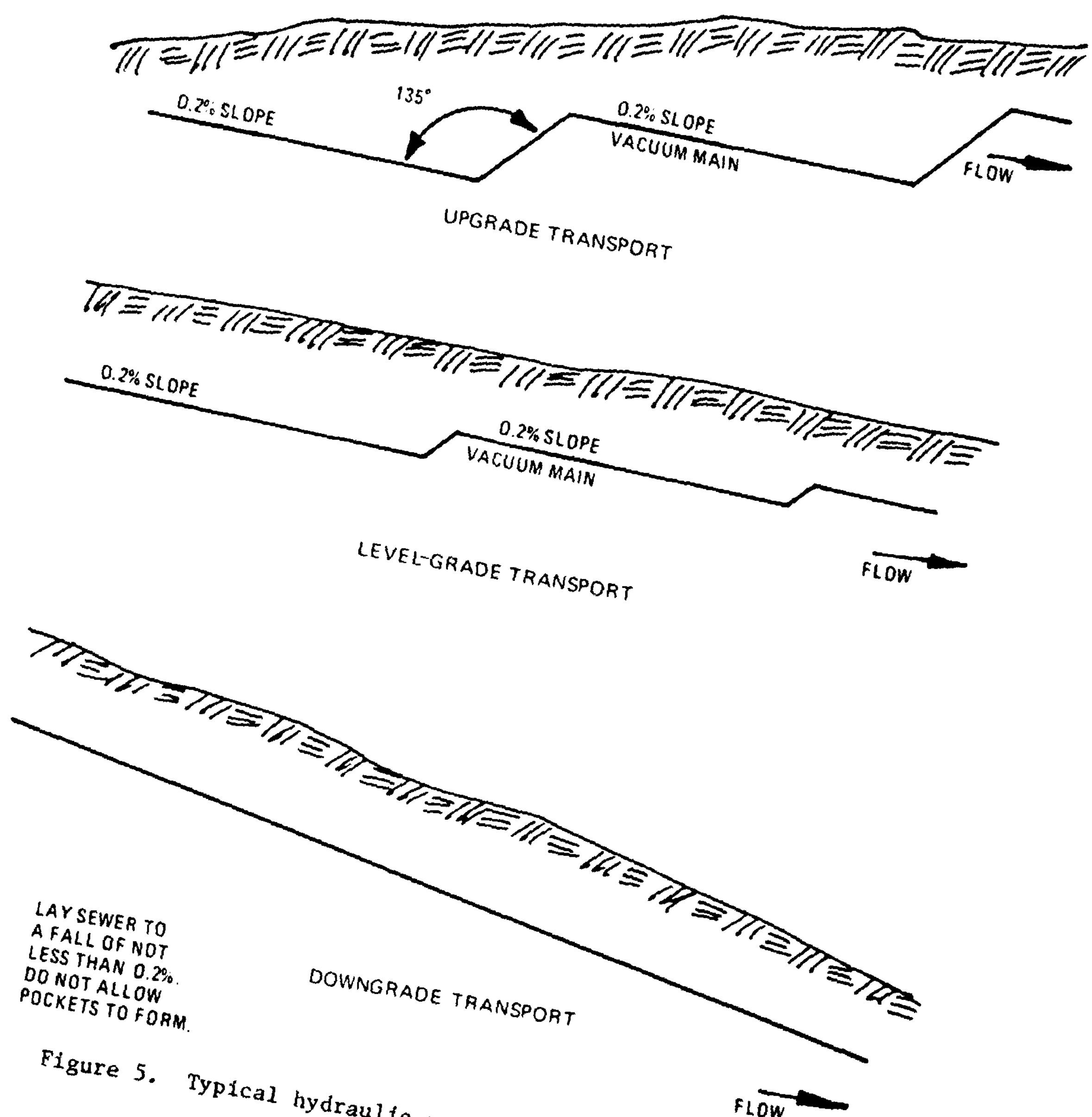


Figure 5. Typical hydraulic profile for vacuum collection systems (from NUCA 1979)

reduced from 50,000 gpd to 13,000 gpd and savings of $74,000 were reported (Envir-O-Pak 1979).

78. It should be mentioned that the Blue Marsh Lake project had initial problems because of a severe underestimate of visitation. System redesign, however, corrected the initial problem. Therefore, it may be stated that vacuum systems are generally more sensitive to errors in design flow and future system expansions would be more difficult than with conventional gravity sewer systems.

Small-Diameter Gravity Systems

79. The application of small-diameter gravity sewers has not received widespread attention in the United States. The only reported application in the United States is in the town of Westboro, Wisconsin (NUCA 1979).

System components

80. Small-diameter gravity systems consist of on-site septic tanks that drain into small-diameter PVC gravity sewers. Lift stations may be required in hilly terrain. Conventional septic tanks are included as a pretreatment method at each waste input point. The septic tanks remove settleable solids and large objects.

81. The hydraulic design of small-diameter systems is similar to that associated with conventional gravity collection systems. The removal of settleable solids prior to entry into the piping system enables the designer to reduce the minimum acceptable wastewater velocity to 1.5 fps. This compares with the traditional 2.0 fps used in design of conventional gravity systems. The smaller pipe diameters, however, require steeper slopes, 0.0067 to 0.0033 ft/ft compared with 0.0040 to 0.0008 ft/ft used for conventional systems. The steeper slopes associated with small-diameter systems may necessitate more lift stations or deeper excavation than for conventional gravity systems.

82. The use of septic tanks at each point of wastewater entry tends to attenuate peak flows, resulting in less conservative design of the piping system. However, the use of septic tanks means that the

system is handling a septic wastewater. Thus, increased corrosion problems may be anticipated.

System costs

83. System costs for small-diameter systems have not been developed in great detail. The bid for the conventional gravity system designed for Westboro is reported to have been 30 to 40 percent higher than the cost for the installed small-diameter gravity system.

84. A major cost of the small-diameter gravity collection system is the septic tank at each wastewater entry point. Septic tanks are generally estimated to cost between $1,000 and $2,000 installed for a household size service. Larger community septic tanks cost proportionately more.

85. Piping costs are expected to be similar to those for gravity sewer systems and will be a function of depth of burial. The estimated installed cost (July 1980) of PVC sewer pipe (6-in. diam) is presented in the following tabulation.

Depth of Burial ft	Estimated Cost dol/lin ft
0 - 6	6 - 8
6 - 8	8 - 11
8 - 10	9 - 12
12 - 14	11 - 14
14 - 16	13 - 18

86. The costs of lift stations associated with small-diameter gravity systems are essentially the same as those associated with conventional gravity systems. Submersible pump stations in the expected flow range are estimated to cost between $9,000 and $12,000 whereas the cost of traditional wet-pit self-priming pumping stations will range between $12,000 and $17,000.* Complex geology or site conditions may substantially increase the cost of such construction. Costs presented

* Personal communication dated 15 July 1980 from Mr. Charles Stone, Missssippi Pump and Equipment Co., Jackson, Miss.

are based on July 1980 manufacturers' quotes.

Evaluation of I/A Systems

87. Three I/A wastewater collection systems are currently available for direct application to recreation area requirements. The relative merits of each are summarized as follows (NUCA 1979).

Pressure systems

88. In comparison with conventional gravity and other collection systems, pressure sewers (both GP and STEP) have disadvantages that could preclude their use in normal terrain.

- a. Conventional gravity sewers will usually be more cost-effective than pressure sewers.
- b. Corrosion problems at treatment facilities, due to septic sewage from pressure collectors, may become prevalent and will increase operation and maintenance demands at the treatment facility.
- c. Pressure systems, because they are designed to flow full, will have limited potential to handle future growth and thus are best suited for stable developments.
- d. Due to the positive pressure inside the collectors, pipe leakage will cause sewage contamination of the surrounding soil and/or groundwater.
- e. STEP systems require regular septage pumping.
- f. Pressure systems are totally dependent upon power and, hence, susceptible to power outages.

89. Where excavation or design of conventional gravity sewers makes them prohibitively expensive (in areas with very hilly or very level terrain, shallow bedrock, or high groundwater), pressure sewers may become a viable alternative. Several advantages associated with pressure sewers are as follows:

- a. Pressure sewers can transmit wastes from 50 to 100 ft uphill and are thus ideal for lakeside and very hilly developments.
- b. Only shallow excavation is required. In areas with shallow bedrock or high groundwater, this may be a crucial economic factor. The extensive surveying associated with gravity systems is not necessary.

c. Infiltration is eliminated in the positive pressure collectors.

d. With STEP systems, the attendant BOD and suspended solids removal may allow reduction in treatment plant size.

e. Pressure systems minimize the dependence of facility siting upon natural topography.

Vacuum systems

90. In comparison with other collection systems, vacuum sewers will have limited applicability in most situations:

a. Vacuum sewers will normally be less cost-effective than conventional gravity sewers, with operation and maintenance costs of vacuum systems being the major determining factor. Replacement of on-site valves every 10-15 years will present a major expenditure.

b. The utility of vacuum sewers in many instances is limited by the necessary constraints upon maximum sewer length, lift, and size of system served.

c. As with pressure sewers, vacuum systems are energy-intensive. Power failures may cause flooding of the collectors after power is regained, due to excess wastewater accumulation in holding basins.

d. Vacuum systems have limited add-on growth potential.

91. When gravity sewers become prohibitively expensive due to terrain or excavation problems, vacuum systems should be considered as an alternative. Several features of vacuum systems should be considered in the alternative analysis:

a. A centralizied vacuum power source is advantageous compared with on-site power sources, as found in pressure systems.

b. Infiltration/inflow may be slightly greater in vacuum systems than in pressure systems, but much lower than in gravity systems. Due to the negative pressure in the vacuum mains, contamination problems due to pipe break or leaks will be minimal.

c. As with pressure sewers, on-site components represent an important fraction of the system cost.

d. Excavation for vacuum system piping will be slightly more expensive than for pressure system piping due to profiles used for vacuum mains.

e. Vacuum toilets represent a substantial reduction in water consumption. In areas where water supply is limited, vacuum systems may be desired for this capability.

f. Vacuum sewage is transported under aerobic and turbulent conditions, resulting in completely mixed and well-aerated sewage. Thus, corrosion problems at the treatment facility are minimized.

Small-diameter gravity systems

92. In comparison with conventional gravity sewers, small-diameter gravity systems have several advantages:

a. Lower capital costs are associated with small-diameter piping.

b. Lift stations for small-diameter systems will be less expensive than those for conventional gravity systems because solids handling capability is unnecessary. However, this capital cost savings may be negated by corrosion problems associated with the septic wastewater.

c. The size and capital costs of treatment facilities may be reduced due to removal of suspended solids and BOD in the septic tank. As with lift stations, this may be negated by corrosion problems.

d. In communities already partially or totally served by septic tanks, small-diameter systems may be very inexpensive to install.

93. Small-diameter gravity sewers have several disadvantages associated with their use:

a. Since only one small-diameter system has been implemented in the United States, little technical expertise exists for this system. Before this alternative is considered for application, system hydraulics and long-term operational capabilities must be researched.

b. Septic tanks must be pumped at regular intervals to ensure that no solids escape into the collectors. Past experience with septic tanks has indicated that homeowner ignorance of or negligence in septic tank maintenance requirements has led to widespread misuse.

c. Septicity of wastewater will cause corrosion problems at lift stations and treatment facilities.

d. Due to the steeper slopes, small-diameter systems are always more sensitive to terrain and excavation problems than conventional gravity sewers, which are normally less expensive. Thus, small-diameter systems will retain an economic disadvantage in comparison with conventional systems, regardless of siting conditions.

e. Growth potential of small-diameter systems is restricted.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

94. A number of conclusions can be drawn from the information collected during the initial year of research into I/A collection systems. These are discussed in the following paragraphs.

95. I/A wastewater collection systems may provide a cost-effective solution to waterborne transport of waste materials generated in recreation areas. Generalized recommendations cannot be made; however, the applicability of an I/A collection system must be assessed on a site-specific basis.

96. Pressure sewer technology is well developed and has substantial applicability in CE recreation areas. System design procedures have been developed for traditional community applications and require modification for use in recreation areas. Both GP and STEP pressure systems are suitable for recreation area use. For small flow-generating facilities, STEP systems may offer the advantages of reduced operation and maintenance over GP systems.

97. Vacuum sewer technology is not as well developed and accepted as pressure sewer technology. Vacuum sewer technology has been implemented at three CE projects and appears to work well when adequately designed. Implementation of vacuum sewer technology may result in substantial cost savings because of the low-water-use fixture normally associated with such systems.

98. The limited experience with small-diameter gravity sewers necessitates additional development prior to widespread CE application.

99. Although design concepts have been substantially developed, each manufacturer offers somewhat different design criteria. A concise single-source design reference is not available and is a major obstacle to adequate evaluation of I/A collection systems.

100. I/A collection cost data, particularly operation and maintenance cost data, are lacking in both reliability and detail. Cost data must be developed in close coordination with equipment manufacturers.

Recommendations

101. Based on the initial evaluation of information gathered to date, the following recommendations are considered appropriate.

102. I/A collection system technology should be evaluated against conventional gravity sewer technology for application at each CE recreation area where new sanitary facility construction is anticipated.

103. A single-source design reference should be compiled for distribution to CE field operating activities. The design guidance should be adapted to the unique constraints associated with recreation area development and include information concerning equipment selection, hydraulic design, materials of construction, and costs.

104. Existing CE installations of I/A collection systems should be monitored to assess the cost of operation and maintenance associated with such systems. Baseline data should also be collected on conventional gravity sewer systems.

REFERENCES

American Society of Civil Engineers. 1974. "Design and Construction of Sanitary and Storm Sewers," Manuals and Reports on Engineering Practice No. 37, New York, N. Y.

Envir-O-Pak. 1979. "Water and Wastewater Equipment Sales and Design Manual," Willow Grove, Pa.

GLUMRB (Great Lakes-Upper Mississippi River Board of State Sanitary Engineers). 1978. "Recommended Standards for Sewage Works" (Ten State Standards), Health Education Service, Albany, N. Y.

Hydr-O-Matic Pumps. 1978. "Pressure Sewer System Manual and Engineering Guide," Ashland, Ohio.

Kriessel, J., Cooper, I. A., and Reyek, J. W. 1977. "Alternatives for Small Wastewater Treatment Systems: Pressure Sewers/Vacuum Sewers," EPA 625/4-77-011, U. S. Environmental Protection Agency, Cincinnati, Ohio.

Metcalf and Eddy, Inc. 1972. Wastewater Engineering, McGraw-Hill, New York, N. Y.

National Utility Contractors Association. 1979. "Evaluation of Wastewater Treatment Alternatives for Small Communities," Energy and Environmental Analysis, Inc., Washington, D. C.

Peabody Barnes, Inc. 1977. "Effluent Pressure Sewer Systems," Paper presented at the Water Pollution Control Federation Conference, Philadelphia, Peabody Barnes, Inc., Mansfield, Ohio.

Skillman, E. P. 1979. "Design Criteria for Vacuum Wastewater Transfer Systems in Advanced Base Applications," Technical Note N-1554, U. S. Navy Civil Engineering Laboratory, Port Hueneme, Calif.

Office, Chief of Engineers, U. S. Army. 1980. "Design of Small Systems Wastewater Treatment Facilities," EM 1110-2-501, Part 2 of 3.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Cullinane, M. John, Jr.
  Innovative/alternative wastewater collection systems for Corps of Engineers recreation areas / by M. John Cullinane, Jr. (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). -- Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1981.
  [illegible] p. : ill. ; [illegible] cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; EL-81-7)
  Cover title.
  "September 1981."
  "Prepared for Office, Chief of Engineers, U.S. Army under Work Unit [illegible]."
  Final report.
  Bibliography: p. 36.

  1. Recreation areas. 2. Sewage disposal. 3. Waste disposal in the ground. I. United States. Army. Corps of Engineers. Office of the Chief of Engineers. II. U.S. Army Engineer Waterways Experiment Station. Environmental

Cullinane, M. John, Jr.
  Innovative/alternative wastewater collection : ... 1981.
(Card 2)

Laboratory. III. Title IV. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; EL-81-7.
TA7.W34m no.EL-81-7

DATE

FILMED